Active Project (2012 - 2017)

National Robotics Initiative (NRI) Project

Game Changing Development Program | Space Technology Mission Directorate (STMD)

ANTICIPATED BENEFITS

To NASA funded missions:

IHMC: Toward Humanoid Avatar Robots. The Robot Operating System (ROS) software, updated under the Open Source Robotics Foundation (OSRF) grant, was used as the OS for controlling Robonaut 2's legs. The flight certified legs, which were delivered to ISS in early 2014, will be attached by the astronauts during several scheduled Robonaut upgrade sessions between July and August 2014. The IHMC walking software has become the baseline for the R5/Valkyrie robots walking, which will be used as part of the joint Centennial Challenges/HRS Space Robotics Challenge

To NASA unfunded & planned missions:

Long-Range Prediction of Non-Geometric Terrain Hazards for Reliable Planetary Rover Traverse could provide means for future Mars or Lunar rovers to detect soft soil hazards before they enter an area, thereby preventing the loss of an expensive vehicle that could otherwise be mired.

To other government agencies:

The walking algorithms developed under the grant to the IHMC are being used to provide walking capability in NASA's R5 robot, developed for the DARPA Robotics Challenge (DRC), which will benefit DARPA as well. The interfaces and controls being developed under the Humanoid Avatar Robots for Co-Exploration of Hazardous Environments have the potential to lay the ground work for human controllers to be able to control humanoid robots for use in hazardous environments such as fire control, search and rescue, and disaster response, which would benefit multiple government agencies and entities. In addition, due to the agreement under the NRI, all R&D performed under any of the funding agencies (currently consisting of NASA, the NSF, the NIH, and the USDA) will be shared across agencies. So the NSF and NIH will have access to new robotics technologies for science and medical applications and the USDA will have access to the for application to robotic agriculture

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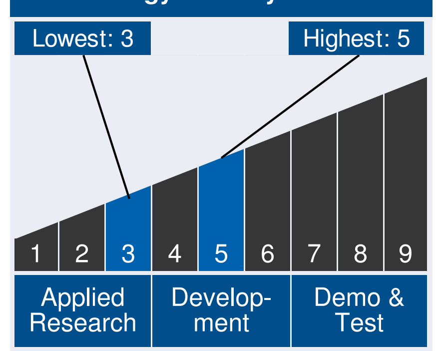
Technology Maturity



applications.

To the commercial space industry:

Long-Range Prediction of Non-Geometric Terrain Hazards for Reliable Planetary Rover Traverse could provide means for future Mars or Lunar rovers to detect soft soil hazards before they enter an area, thereby preventing the loss of an expensive vehicle that could otherwise be mired.

To the nation:

These grants provide R&D funds to U.S. universities and labs to advance different aspects of robotics within the U.S., which will help achieve the president's goal of creating new markets in the U.S. for robots assisting humans. In addition, many of the robotic technologies being matured under these grants could help save lives when applied in the use of robots for search and rescue, use of robots as health monitoring assistants, or through robotic applications in surgery, once the technology has fully matured.

DETAILED DESCRIPTION

The National Robotics Initiative (NRI) is a cross-governmental, joint solicitation managed for NASA by HRS to keep the US competitive in the field of robotics. NRI is coordinated through the National Science Foundation, with funding from participant agencies, including NASA, NIH, USDA, DARPA, and DoD. NASA grantees mature robotics capabilities in any of the seven TA04 Robotics areas, accelerating development of next-generation robots to keep the U.S. at the leading edge. Participant agencies share the results of all research, multiplying their ROI.

Management Team

Program Executive:
- Lanetra Tate

Program Manager:
- Mary Wusk

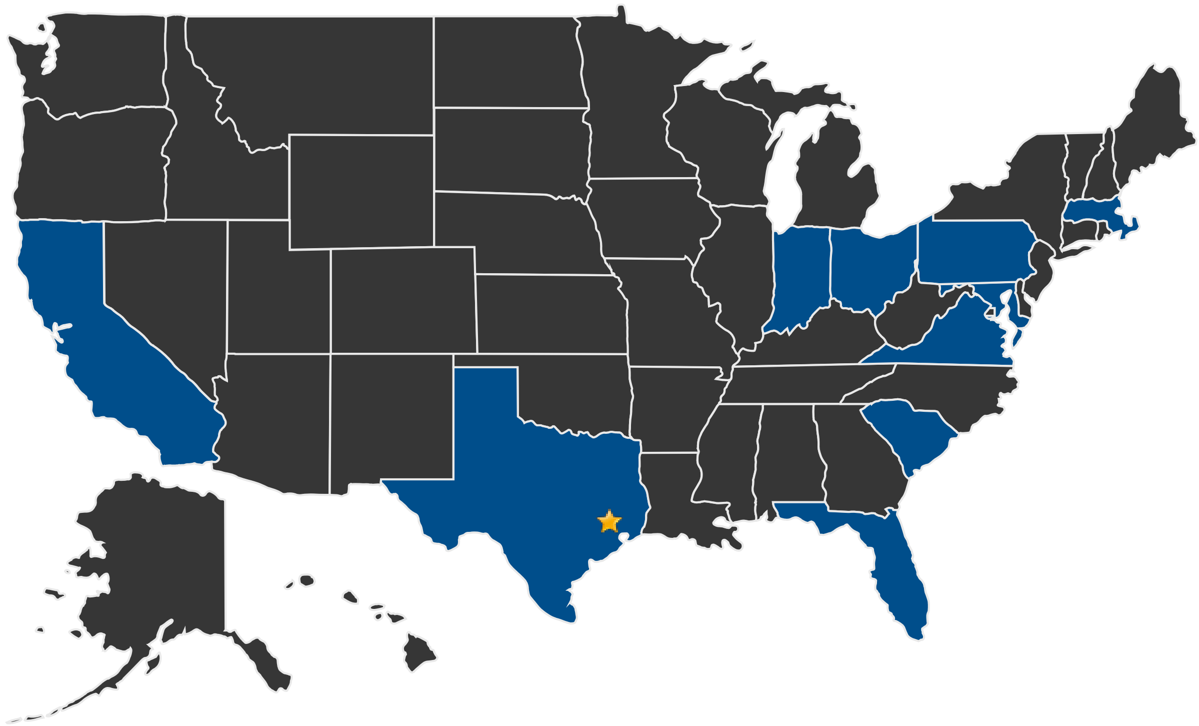
Project Manager:
- William Bluethmann

Principal Investigator:
- Robert Ambrose

Technology Areas

- Robotics and Autonomous Systems (TA 4)
- Human-System Interaction (TA 4.4)
- Interaction Architecture (TA 4.4.5.1)

U.S. WORK LOCATIONS AND KEY PARTNERS



U.S. States With Work

Lead Center:
Johnson Space Center

Other Organizations Performing Work:

- Carnegie Mellon University
- Clemson University
- Florida Institue for Human and Machine Cognition
- Georgia Institute of Technology
- Massachusetts Institute of Technology
- National Science Foundation
- Northeastern University
- Northwestern University
- Open Source Robotics Foundation (Mountain View, CA)
- Purdue University
- The University of Texas at Austin
- University of Maryland, College Park

DETAILS FOR TECHNOLOGY 1

Technology Title

A Novel Powered Leg Prosthesis Simulatior for Sensing and Control Development

Technology Description

This technology is categorized as a hardware system for ground scientific research or analysis

Develop leg prosthesis simulator capable of applying specific model-predicted torques to both prosthetic & residual limbs of amputees (also applicable to robot / exoskeleton legs) to provide prosthetics and robotics designers the simulation tools and data necessary to allow creation of prosthetics / robotic limbs that more closely imitate the motion of the human leg.

Capabilities Provided

The leg prosthesis simulator, when fully matured, will be capable of applying specific model-predicted torques to both prosthetic & residual limbs of amputees, as well as to robotic or exoskeleton legs. This will provide prosthetics and robotics designers the simulation tools and data necessary to allow creation of prosthetics / robotic limbs that more closely imitate the motion of the human leg.

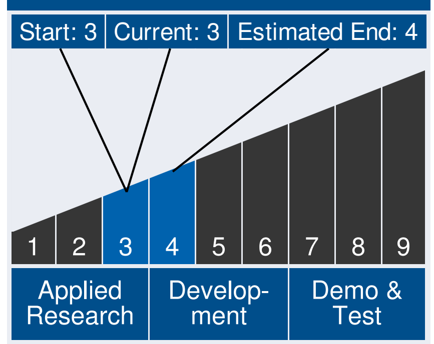
Potential Applications

The fully matured prosthetics simulator will provide prosthetics and robotics designers the simulation tools and data necessary to allow creation of prosthetics / robotic limbs that more closely imitate the motion of the human leg. The main goal of the researcher is to develop the tools necessary for creating the next generation of prosthetic limbs for amputees, first for trans-tibial, and then later one for trans-femural amputees. This technology is directly applicable to the development of future legs for NASA's humanoid robots such as Robonaut 2 and R5 as well.

Technology Areas

Primary Technology Area:
Robotics and Autonomous Systems (TA 4)
└ Human-System Interaction (TA 4.4)
  └ Distributed Collaboration and Coordination (TA 4.4.5)
    └ Interaction Architecture (TA 4.4.5.1)

Technology Maturity



DETAILS FOR TECHNOLOGY 2

Technology Title

Active Skins for Simplified Tactile Feedback in Robotics

Technology Description

This technology is categorized as a hardware subsystem for ground scientific research or analysis

Create soft, conformable, robotic skin with active embedded sensors and processing, which will allow a robot to easily acquire and interpret tactile data. Significant research has been focused on tactile sensing in the last decades, but very little research has considered the system challenges for robot skins. This research specifically addresses these challenges by incorporating compliant wiring in the skin structure and embedded control to relay abstracted touch concepts to higher level controllers. The scalability of compliant skins is also addressed by developing fabrication methods that can scale from high density fingertips to large area arrays for robotic arms or bodies.

Capabilities Provided

This technology, when fully matured, will provide a conformable membrane or skin with embedded sensors, which can be placed over the outside of a robot (for example over its fingers), providing the ability to gather and interpret tactile data, in essence, giving it a sense of touch.

Potential Applications

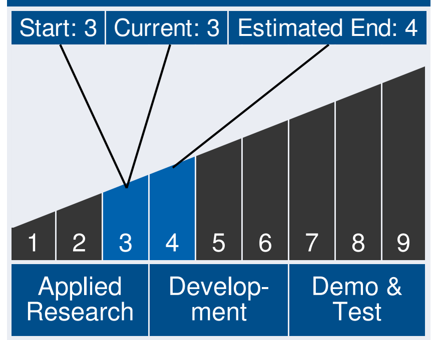
If successful, the results of this research will lead to the first robots that can integrate large amounts of spatially distributed touch information at low cost (money, time and integration) to better interact with humans.

The applications for robots with a sense of touch are almost endless, and include:

Technology Areas

Secondary Technology Area:
Robotics and Autonomous Systems (TA 4)

Technology Maturity



- Co-robots to assist astronauts in space and one other worlds
- Industrial robots that can perform dexterous manipulation of thin deformable materials like cloth
- Medical robots that can perform surgery
- Home-care robots that can safely interact with humans, helping them up, supporting them, or even carrying them when injured

DETAILS FOR TECHNOLOGY 3

Technology Title

Actuators for Safe, Strong, and Efficient Humanoid Robots

Technology Description

This technology is categorized as firmware for ground scientific research or analysis

Rigorously address multi-objective optimization of actuators used in humanoid robots to provide a means to design actuators that are on the boundary of theoretically achievable performance. In parallel, investigate permanent magnet ac machines, permanent magnet dc machines, switched reluctance machines, and wound-rotor synchronous machines.

Capabilities Provided

This research conducted in this project will:

- Provide a rigorous approach to custom design of actuators tailored to specific joint function
- Determine the boundaries of achievable performance for several existing and novel actuator drive topologies

Potential Applications

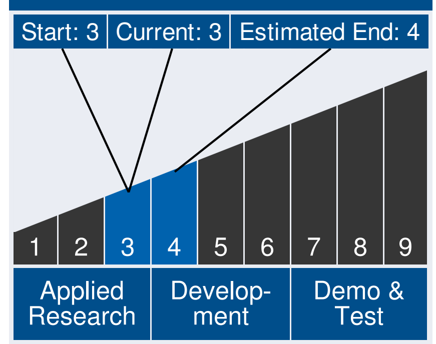
It is expected that actuators that are formally optimized for specific joint function will lead to a significant increase in the strength, endurance, and mass reduction of humanoid robots. Potential applications include:

- For space exploration, this offers the potential to enhance the profile of robot- and human/robot-based missions.

Technology Areas

Secondary Technology Area: Robotics and Autonomous Systems (TA 4)

Technology Maturity



- For earth-based applications, the performance gains and size reduction will further the development of robots intended for human interaction.
- In addition, the approaches and new motor technologies developed herein are transferable to the optimization of prosthetic joints which offers the potential to greatly improve their performance as well.
- Finally, new projects based upon actuator design will be integrated into both undergraduate and graduate courses, effectively transferring the knowledge to many generations of students

DETAILS FOR TECHNOLOGY 4

Technology Title

Building the Robotic Commons - Open Source Robotics Foundation (OSRF)

Technology Description

This technology is categorized as an operating system for ground scientific research or analysis

Support the Open Source Robotics Foundation (OSRF) in the continued development of the Robot Operating System (ROS), Gazebo, and other open source robotics software used by NASA and the robotics community. Designed for both robotics researchers and application developers, ROS is already widely used around the world in classrooms, labs, and companies, and is used on a number of robotic assets across NASA, including the operating system for controlling the ISS IVA legs for Robonaut 2. Gazebo is used for simulating robots on the ground during development, and is used for R2 simulations.

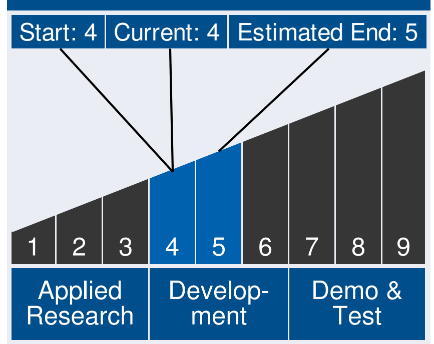
Capabilities Provided

Under this grant, OSRF will improve, test, distribute, and support the Robot Operating System (ROS), the robot simulation software, Gazebo, and other open source robotics software used by NASA and the robotics community. The OSRF will focus development on the following critical, presently under-served, areas:

Technology Areas

Secondary Technology Area:
Robotics and Autonomous Systems (TA 4)

Technology Maturity



- Shared autonomy in the Robot Operating System (ROS) software
- Improved platform support in ROS

Potential Applications

The fully matured software release will provide NASA and the worldwide robotics community with freely available open source tools that will enable a generation of robotics students, developers, entrepreneurs, and enthusiasts to more quickly and easily realize their aspirations. Just as the availability of the open source LAMP stack (Linux, Apache, MySQL, and Perl/PHP/Python) enabled the internet revolution in the 1990’s, the software resulting from this project has the potential to revolutionize the robotics industry, producing an environment that fosters a kind of innovation that we cannot fully anticipate today.

DETAILS FOR TECHNOLOGY 5

Technology Title

Long, Thin Continuum Robots for Space Applications

Technology Description

This technology is categorized as a hardware assembly for ground scientific research or analysis

This grant provides funding for R&D in the area of long, thin, continuous backboned or “continuum” robots to solve problems of interest to NASA, such as improved ability to penetrate and maneuver within environments filled with obstacles, requiring multiple tight turns in a series of increasingly complex and narrow obstacle fields.

Capabilities Provided

- Improved ability to control long thin robots
- Improved ability for long thin robots to penetrate and maneuver within confined spaces filled with obstacles

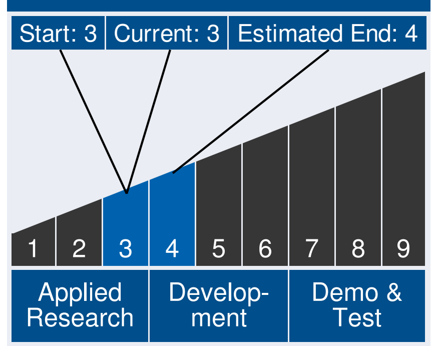
Potential Applications

This technology is applicable to the creation and control of long, thin, robots with visual or other sensors on the end, which are of interest to NASA for providing a means to quickly and easily inspect behind computer racks and other hardware on the

Technology Areas

Secondary Technology Area:
Robotics and Autonomous Systems (TA 4)

Technology Maturity



International Space Station for signs of damage, electrical hazards, fluid leaks, micro hull penetrations, etc.

Potential terrestrial applications include long thin robots for use in fields such as: search and rescue, where they could worm their way through collapsed structures in search of survivors; and health care, where they could potentially be used for orthoscopic surgical procedures.

DETAILS FOR TECHNOLOGY 6

Technology Title

Long-Range Prediction of Non-Geometric Terrain Hazards for Reliable Planetary Rover Traverse

Technology Description

This technology is categorized as a hardware subsystem for ground scientific research or analysis

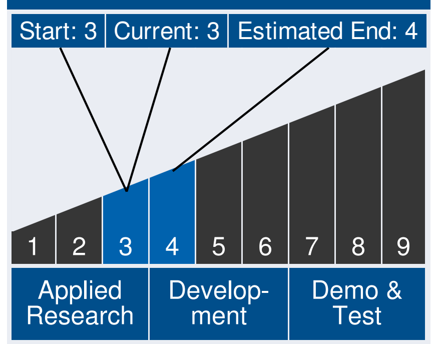
Non-geometric terrain hazards are mission-enders for autonomous ground vehicles on Earth and on other worlds. Spirit was mired in soft soil on Mars and Lunokhod became stuck in regolith on the Moon. Autonomous ground vehicles must detect and react to off-nominal conditions to limit risk and maximize performance. This research investigates multiple sensing modes for short- and long-range terrain property measurement by incorporating long-range sensing and receding horizon control to ensure safe operation during autonomous planetary traverse, allowing robots to perceive and react to non-geometric terrain hazards, such as soft soil, before engaging them.

This research takes a two-pronged approach, incorporating long-range sensing and receding horizon control to ensure safe operation during autonomous planetary traverse. It will investigate and develop detection of non-geometric hazards with multiple sensing modes to ascertain terrain properties at range. Self-supervised learning maps multi-mode long-range sensor data to terrain properties, measured by direct-contact instruments, and to observed vehicle performance. Receding

Technology Areas

Secondary Technology Area:
Robotics and Autonomous Systems (TA 4)

Technology Maturity



horizon contingency planning applies learned models of vehicle-terrain interaction to maintain stability and safety.

Capabilities Provided

This research will enhance knowledge and understanding of robotic driving in unstructured terrain.

This activity will investigate multiple sensing modes that could provide non-geometric terrain hazard estimation from a distance. This will enhance knowledge and understanding of robotic driving in unstructured terrain. Good methods exist for sensing geometric obstacles; the limitation now is non-geometric hazards. Human drivers can infer non-geometric terrain properties well from prior experience, to pilot vehicles near their physical limits. State-of-art computer systems can infer some non-geometric properties at short range but are limited. Research impacts the fields of artificial intelligence, robot perception, and planetary robotics

Potential Applications

Automated perception and reaction to non-geometric hazards have defied autonomous robots. Despite great advances in mechanism, electronics, and software reliability, robots cannot achieve systemic reliability until they perceive and react to terrain hazards before engaging.

When coupled with speed and dynamic effects, hazard assessment is a major barrier to infusion of automated safety features in passenger cars. Fast, robust, predictive assessment of hazard will enable driving, working and exploring near the limits of machine capability.

The fully matured technology could provide future planetary rovers, such as Mars 2020, with the capability to sense non-geometric terrain hazards from a distance, hazards that are not detectible based purely on visually inspection, allowing them to avoid being trapped in loose soil.

Terrestrial search and rescue robots could potentially benefit from this technology as well.

DETAILS FOR TECHNOLOGY 7

Technology Title

Manipulating Flexible Materials Using Sparse Coding

Technology Description

This technology is categorized as firmware for ground scientific research or analysis

Enable dexterous robots to perform flexible materials manipulation, that only human can currently perform, by making

Technology Areas

Secondary Technology Area:
Robotics and Autonomous Systems (TA 4)

it easier and less expensive to create haptic models for use by robots, through the use of force & tactile sensing to localize flexible materials.

Capabilities Provided

The ideas advanced in this proposal could be very significant for autonomous flexible materials manipulation.

- The main hypothesis, that sparse coding will capture “micro-structure” in tactile interactions, could dramatically improve the accuracy of haptic models and therefore make manipulation based on tactile sensing much more practical, if proven to be true.
- The idea of creating haptic models using mapping and optimization techniques could make model-building much easier, by allowing haptic models to be build based on unstructured haptic interactions.
- Finally, the idea of using planning under uncertainty, to combine perception and goal-directed planning, could make manipulation more robust by providing a systematic way of integrating tactile perception into a task.

Potential Applications

This research has the potential of having large impacts on manufacturing and NASA.

- Ability for manufacturing robots to work with flexible materials - Flexible materials and deformable parts are commonplace in US manufacturing applications – yet there is nearly zero capability for assembling these materials automatically using robots. Deformable parts are nearly always assembled by hand. As a result, the potential impact of this work on manufacturing is huge.

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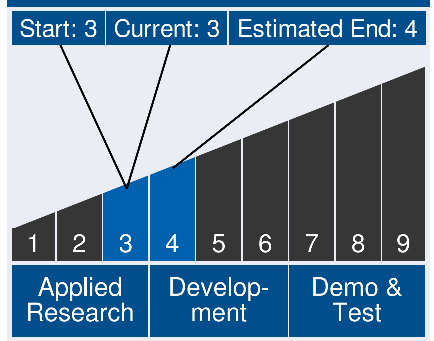
Technology Maturity



- Ability for an EVA Robonaut to remove external thermal blankets at a worksite – Flexible materials are common in NASA applications. The ability to robustly manipulate flexible thermal blankets is essentially a prerequisite for all extra vehicular (EVA) repair work. The successful development of technology based on the proposed ideas would expand the scope of the missions that NASA would be able to perform.

DETAILS FOR TECHNOLOGY 8

Technology Title

Toward Humanoid Avatar Robots for Co-Exploration of Hazardous Environments

Technology Description

This technology is categorized as firmware for ground scientific research or analysis

Extend existing open source robotics software libraries to make them more transparent, directable, and predictable in the avatar system. Improve balance and walking algorithms. Improve humanoid motion planning in complex, dynamic, and unstructured environments, such as the scene of a disaster or surface of another planet. Demonstrate alternate approach to pure tele-operation or pure autonomy. Demonstrate feasibility of using human-humanoid avatar robot teams for co-exploration of hazardous environments using Robonaut 2 as a test-bed.

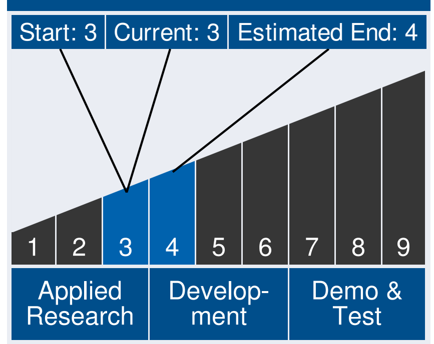
Capabilities Provided

The proposed research will address several unsolved problems in humanoid robot balance and walking algorithms, humanoid motion planning in complex dynamic and unstructured environments, and telepresence interfaces. It will demonstrate an alternate approach to pure teleoperation or pure autonomy. It will demonstrate the feasibility of using human-humanoid avatar robot teams for coexploration of hazardous environments. The fully matured technology under this research task would provide:

Technology Areas

Secondary Technology Area:
Robotics and Autonomous Systems (TA 4)

Technology Maturity



- Coactive interfaces, which explicitly take into account the interdependence of cooperative tasks - Today's robots are typically fully teleoperated, placing a large burden on the operator, or have full autonomy that is opaque, leading to automation surprises.
- Bipedal walking and balance algorithms - Today's best humanoids still fall over from slight pushes, and cannot walk on slightly rough ground without a high-precision model of the ground.
- Humanoid locomotion planning - There are many impressive planning tools available that we will leverage, but work still needs to be done on applying these tools to complex, unstructured, and dynamic hazardous environments, as well as integrating manipulation and dynamic locomotion.
- Multi-sensory telepresence interfaces - Appropriate use of telepresence interfaces that project not only visual, but also tactile and audio information to the operator, may lead to improved situational awareness.

Potential Applications

Search & Rescue / Disaster Recovery Robots – In the near future, this technology could be used to enable humanoid avatar robots to assist in exploration and recovery of disaster sites. While a variety of robots will be used, humanoid robots will fill a special role, since they can potentially get to the same places, perform the same tasks, and use the same tools as humans.

Space Exploration Robots - Remotely operated humanoid avatar robots could one day work cooperatively with humans to explore planetary surfaces and build space colonies.

Inspiration - Human and humanoid avatar co-exploration of hazardous areas and planetary surfaces has the potential to capture the minds and imaginations of current and future scientists and engineers, and the public at large, leading to enhanced educational motivation and national pride.

Open Source Software - This project will involve a variety of post-docs, graduate, undergraduate, and high school students. All developed software will be made open source and freely available. Research will be disseminated and communicated through various means, including incorporation into a University of West Florida class on bipedal walking robots, and existing IHMC informal science education programs.

DETAILS FOR TECHNOLOGY 9

Technology Title

Whole-Body Telemanipulation of the Dreamer Humanoid Robot on Rough Terrains Using a Hand Exoskeleton

Technology Description

This technology is categorized as firmware for ground scientific research or analysis

Develop a control framework for tele-manipulation of low-cost mobile and dexterous robots, keeping humans at the center of the control loop by retargeting low-level exoskeleton gestures to sophisticated humanoid skills, providing NASA with a robust, natural method of tele-operating humanoid robots via a hand exoskeleton force feedback control device worn by the user.

Capabilities Provided

When fully matured, this technology will provide:

- A whole body control paradigm for the adaptive movement and force control of humanoid robots in rough terrains
- A novel hand exoskeleton, based on the idea of human-like variable stiffness, that will provide control commands to the humanoid from an operator
- Development of a bottom-up computational skill’s infrastructure to enable the creation and representation of whole-body compliant tasks, retargeting exoskeleton-based telemanipulation gestures to desire matching frames in desired locations on the robot’s body, and providing safety, reactive response to the environment, and terrain adaptation

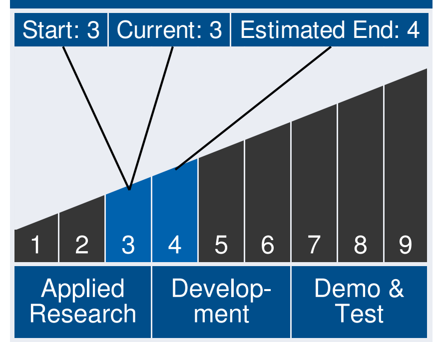
Potential Applications

The fully matured technology will have important broader impacts in robotics research, human-robot interactions, improving manufacturing in the US, and also in education and outreach activities.

Technology Areas

Secondary Technology Area:
Robotics and Autonomous Systems (TA 4)

Technology Maturity



- With a control paradigm for retargeting low level exoskeleton gestures to sophisticated humanoid skills, we will be able to reinforce the design of more effective theoretical and computational methods for improving telemanipulation in lean manufacturing environments.
- Developments from the proposed research program will also lead to dramatic improvements in telemanipulation technology which has applications in space exploration, robotic surgery, and bomb diffusion.
- In addition, the proposed project will create a unique interdisciplinary environment enabling education, training, and co-advising of graduate and undergraduate students, and significant and targeted outreach activities to underrepresented groups in science and engineering.